followed a day later by that from the East Branch. Had all or any two come out together, a serious flood in the lower river would surely have resulted.

The rains of the latter days of February and March 1 caused a moderate flood in the Alabama River, and others somewhat more pronounced in the Black Warrior, the lower Tombigbee, and the rivers of southeastern Mississippi. Warnings were issued for all, and no damage worthy of special mention was done. On some of the rivers the floods were of benefit, as they permitted the movement of lumber that had been held for sufficient water to float it to market.

The heavy rains on March 13 and 14 caused severe and dangerous floods along the upper Potomac River and its headwaters, resulting in damage to the amount of about $1,000,000, mainly to railroad interests. There was no damage of consequence below Cumberland, Md.

High water did some damage along the rivers of Idaho, the result of heavy rains and melting snows.

At the end of the month the Mississippi River was free from ice, which broke up at Leclaire, Iowa, on March 1, and at Fort Ripley, Minn., on March 27.

The rivers of Maine remained frozen, but the ice of the upper Connecticut gave way between March 27 and 29.

The highest and lowest water, mean stage, and monthly range at 312 river stations are given in Table VI. Hydrographs for typical points on seven principal rivers are shown on Chart I. The stations selected for charting are Keokuk, St. Louis, Memphis, Vicksburg, and New Orleans, on the Mississippi; Cincinnati and Cairo, on the Ohio; Nashville, on the Cumberland; Johnsonville, on the Tennessee; Kansas City, on the Missouri; Little Rock, on the Arkansas; and Shreveport, on the Red.—*H. C. Frankenfield, Professor of Meteorology.*

SPECIAL ARTICLES, NOTES, AND EXTRACTS.

RAINFALL AND RUN-OFF OF THE CATSKILL MOUNTAIN REGION.[1]

By THADDEUS MERRIMAN, Assistant Engineer. Dated Browns Station, N. Y., June 14, 1906.

The purpose of the studies on the rainfall and run-off of the Catskill watersheds, the results of which are embodied in this report, has been:

1. To determine the most probable mean annual rainfall on each of the four watersheds proposed to be used as an additional supply for the city of New York.
2. To determine the relation between the values of the rainfall on these watersheds and the values of the rainfall at other points where long and careful records have been kept.
3. To determine as closely as possible the percentage of the rainfall on these watersheds which may be expected to appear as streamflow and become available for the supply of the city.

RAINFALL.

An examination of rainfall records in the State of New York, particularly in the territory covered by the Rondout, Esopus, Schoharie, and Catskill watersheds, at once showed that practically no observations had ever been made in this immediate vicinity. There was found but one record within the limits of these watersheds, and that for a short period only. A number of records had been kept at distances varying from 3 to 20 miles, and located geographically around the area under consideration. An admirable digest of these records in the vicinity was made in the report of the Commission on Additional Water Supply for the city of New York, in 1903. This commission also established a number of gages on these watersheds. Observations were continued for about nine months, when the completion of the work of the commission caused their abandonment.

Ten rain gages have been established by the present Board of Water Supply, and these, in connection with the gages of the voluntary observers of the United States Weather Bureau, cover in excellent form all the territory of the four watersheds. For the future, therefore, the rainfall will be determined with a high degree of precision.

In order to fix the most probable mean value of the rainfall in this territory it was decided to make the study as comprehensive as possible. To this end, therefore, nearly all reliable records for points within approximately one hundred miles of the Ashokan basin which could be found in public documents were gotten out and studied. This work involved an examination of the records at 76 different stations, the records at all of the stations covering a total length of 1085 years.

The records studied were obtained from the following sources: (*a*) New York State Meteorology. (*b*) The New York State Weather Bureau Reports. (*c*) The United States Weather Bureau Reports. (*d*) Records at miscellaneous points, as given in the report of the Commission on Additional Water Supply.

In the New York State Meteorology are assembled the records of observations made at the incorporated academies of the State, under the direction of the regents of the University of the State of New York. These records were begun in 1825 and carried on more or less continuously until the Civil War diverted attention from them, and they were forgotten.

Two different forms of gages were employed by these old-time observers. Prior to 1833 a gage with but little protection against evaporation was used. A conical mouthpiece collected the rain and delivered it into a cylinder the area of which was one-eighth that of the mouth of the collecting cone. In this cylinder there was a float connected to a graduated scale which projected above the top of the gage, and on which the depths were read. In cold weather a vessel having the same area of mouth as the collector of the gage was set out. The snow was caught in this vessel, melted, and measured in the gage. This vessel was not more than 6 inches deep, and it is doubtful if the precipitation during the winter months, as determined by this device, was even of a reasonable degree of accuracy. In fact, an inspection of these records shows that the rainfall during the winter season was then apparently quite uniformly lower than that which is recorded by gages at the present time; there is no reason for believing that such was really the case, and the difference is to be attributed to the type of gage used.

The instructions for setting these gages stated that they should be set remote from all obstacles, and distant from them by at least twice the height of the obstacle.

After 1833 a conical type of gage was used, the details of which are shown in the accompanying sketch.[2] Measurement of the rainfall was made by putting a graduated stick down into the gage. This stick was graduated so as to give a reading in hundredths of an inch for the first three-tenths of an inch, and thereafter by fifths of an inch. The instructions for the setting of these gages were the same as those for the older type, except that they were to be placed with their mouths 8 feet above the surface of the ground.

All of these old records indicate quite uniformly a lower value for the rainfall than do the results of more recent observations. While it is impossible to state absolutely the reasons for this apparent difference, it is probably due (1) to loss by evaporation from the first type of gage used; (2) to the unapproved method of measuring the snowfall; (3) to the placing of the conical gage 8 feet above the ground; this gage would therefore probably register about 3 per cent less rain than the standard gages now in use.

[1] A report to C. E. Davis, department engineer, and J. Waldo Smith, chief engineer, Board of Water Supply, city of New York. Communicated by permission of the Board.

[2] Not reproduced here.—EDITOR.

On the other hand, however, there is nothing to indicate that these reports were not kept with the greatest care and fidelity. They show monthly rainfalls as high as any we have now, and others just as low. Were it not for the unfortunate differences in methods used, these records would be of very great value. In these studies they have been used as having an indicative value only.

The records obtained from the reports of the New York State Weather Bureau and from those of the United States Weather Bureau are the most valuable and reliable which can be obtained. The methods used by the observers reporting to these two bureaus are uniform, and the only question which can arise as to their reliability is that of the unfaithfulness of the observers. This naturally is something which can not be considered.

To attempt to assign a relative value to the records of all the stations studied would be a hopeless and impossible task. They have, therefore, been studied collectively; i. e., when in one locality one record showed a very high value and another a low one the mean of the two records has been considered as being the most probable value of the rainfall in that vicinity. Having decided that this was the only practical method of treating the records studied, it was felt that before even this could be done they must be reduced to some more even plane. The following is the reasoning which was used in this deduction, the steps of which are shown in detail in Tables 1 and 2.

Rainfall is erratic, and follows no definitely recognized law. Records of rainfall may differ from each other on account of what we may term "accidents of location", such, for instance, as the inapparent effect of a building; or again, the location of the gage in the path of showers, which path is defined by the topography of the country; or the results may differ, as from a minor local storm, which is felt at one station and not at another. That such differences occur is well shown by a study of the contemporaneous rainfalls at New York and Newark, 10 miles distant from each other, and again at Albany and Troy, but 7 miles apart. These very visible differences led us to an extended study, and we observed that they occur usually in the months of June, July, August, September, and October. Those which occur in June, July, and August are probably the result of local thundershowers, while those of September and October seem to be due to extended storms which cover a wide area of country, yet in which the precipitation varies greatly, even over a limited portion of territory. Other differences, not numerous, however, occur in the other months of the year, but the reasons for them are not so apparent.

Having recognized and admitted this principle of permissible differences in the records, the following method of rendering them comparable presented itself. Any monthly rainfall which exceeds twice the monthly mean rainfall for the length of the record is an excessive or unusual rainfall, and should be eliminated from the record. This has been done in the following manner: In any month in which the rainfall exceeded twice the monthly mean, as before defined, the value used for that month was the monthly mean, unless the rainfall for either the preceding or the following month was less than one-half its monthly mean, in which case only the excess of the surplus of the one month over the deficiency of the two months was deducted. The value of the yearly rainfall so determined has been called the "mean annual dependable" rainfall. It is not felt that this method of treating the records departs from sound and logical principles. It is without doubt a conservative assumption, and for that reason has recommended itself most strongly.

Rainfall, according to the best of our knowledge, varies in irregular cycles. It appears to be manifestly improper, therefore, to compare even the mean annual dependable rainfall at one station with that at another without reducing them both to an even plane by correcting them after comparison with the contemporaneous rainfalls at one or more points where records have been kept both for a long period and in an efficient manner. New York and Newark on the south, and Albany and Troy on the north, seemed to answer this purpose, and, following still further the method of elimination of differences in record due to local conditions, the mean annual dependable rainfalls for New York and Newark were averaged, and the resulting value called the mean annual dependable rainfall in the vicinity of New York. Similarly, the values of the mean annual dependable rainfall at Albany and Troy were averaged and called the mean annual dependable rainfall in the vicinity of Albany.

The values of the mean annual dependable rainfall at all stations studied have therefore been increased or diminished as the mean annual dependable rainfall in the vicinity of New York and in the vicinity of Albany varied above or below its mean during the years of the record in question. Two values for the deduced mean annual dependable rainfall at each station were thus obtained, and their mean was taken as most probably giving the best value. The full detail of this method is shown in Table 2. The value for the rainfall so determined has been called the "deduced mean annual dependable rainfall".

In the foregoing treatment the probability that the rainfall at any station within a given area varies from its mean by practically the same percentage as does the rainfall at any other station within the area has been made use of. In substantiation of this principle, Table 3 is presented. This table indicates that this proposition is true for 72 per cent of the time within the area covered by the records studied, and it may be added that the smaller the territory under consideration the more nearly does it become absolute.

Having obtained the values of the deduced mean annual dependable rainfall as before described, even they did not appear to be proper values to use for the purpose of drawing isohyetal lines on a map of the region, for the reason that the mean annual dependable method had practically eliminated all local characteristics. In Table 1, therefore, will be found the number of unusual years, the records of which have been modified by this method. The percentage which the number of these unusual years is of the length of the record was then determined, as also the difference between the mean annual and the mean annual dependable precipitation. The product of this percentage and this difference was then added to the deduced mean annual dependable precipitation in order to determine finally the most probable value of the mean annual rainfall.

This value having been determined, it was plotted for all stations, and the isohyetal lines drawn as shown on the map, fig. 1. In studying these lines in connection with the values of the rainfall in Table 1, it must be borne in mind that the old records were given an indicative value only, and that where two neighboring stations showed different values for the rainfall the mean of these two values was taken as being the best value for that vicinity.

These lines indicate that the most probable values of the mean annual rainfall for the four watersheds under consideration are as stated in the first column of the following table of probable rainfall:

Watershed.	Map.	Additional water supply.	U. S. Weather Bureau.
	Inches.	*Inches.*	*Inches.*
Rondout	48	49	47
Esopus	44	46½	43
Schoharie	41	42	39
Catskill	39	39½	37

For purposes of comparison the values for the mean annual rainfall on these watersheds, as deduced by the Commission on Additional Water Supply, and the values as determined from the curves of mean annual rainfall published in the annual summary for 1905 of the New York section of the Climate and Crop Service of the United States Weather Bureau, are also given.

TABLE 1.—*Showing all the stations for which records have been studied, the time of these records and their length, the number of extraordinary falls occurring during the life of the record and the percentage which such occurrences are of the length of the record, the mean annual precipitation as usually deduced, the mean annual dependable precipitation and the difference between them, the deduced mean annual dependable precipitation and a quantity which is the product of the percentage of the extraordinary falls and the difference between the mean and mean dependable precipitation; this quantity is properly added to the mean annual deduced dependable precipitation in order to give finally a most probable value for the mean yearly rainfall.*

Place.	Time of record.	Length of record.	Number of extraor'y falls.	Per cent of extraor'y falls.	Mean annual precipitation.	Mean annual dependable precipitation.	Difference.	Deduced mean annual dependable precipitation.	Quantity to be added.	Probable mean yearly rainfall.
		Yrs.			*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
New York, N. Y.	1836–1905	70	23	33	45.86	43.71	2.15	43.71	0.71	44.42
Newark, N. J.	1844–1904	61	15	25	47.57	44.62	2.95	44.62	0.74	45.36
Albany, N. Y.	1825–1904	80	24	30	38.89	37.31	1.58	37.31	0.47	37.78
Troy, N. Y.	1826–1886	59	17	29	36.45	35.18	0.64	35.18	0.19	35.37
Croton watershed, N. Y.	1868–1904	37	14	38	49.04	46.73	2.31	45.91	0.88	46.79
Pequannock, N. J.	1893–1905	13	4	31	50.84	47.71	3.13	48.95	0.97	49.92
Le Roy, Pa.	1889–1905	17	2	12	40.66	40.12	0.54	40.47	0.06	40.53
Dyberry, Pa.	1866–1898	25	0	0	39.00	39.00	0.00	38.22	0.00	38.22
Blooming Grove, Pa.	1866–1894	27	14	52	43.68	39.80	3.88	39.30	2.02	41.32
Towanda, Pa.	1896–1905	10	1	10	35.66	35.20	0.46	35.82	0.05	35.87
Easton, Pa.	1857–1905	26	8	31	45.68	43.71	1.97	43.23	0.61	43.84
Mauch Chunk, Pa.	1890–1905	14	3	21	50.29	48.74	1.55	49.46	0.33	49.79
South Eaton, Pa.	1890–1905	16	1	6	38.32	37.99	0.33	38.87	0.02	38.89
Salem Corners, Pa.	1870–1899	9	0	0	48.39	48.39	0.00	47.21	0.00	47.21
Bethlehem, Pa.	1878–1903	26	6	23	44.06	42.19	1.87	43.17	0.43	43.60
Coopersburg, Pa.	1890–1900	11	1	9	47.29	46.48	0.81	47.67	0.07	47.74
Wilkes-Barre, Pa.	1885–1905	17	4	24	40.28	38.84	1.44	39.57	0.35	39.92
Honesdale, Pa.	1882–1894	13	3	23	45.64	41.75	3.89	40.42	0.89	41.31
Belvidere, N. J.	1892–1904	11	3	27	47.33	45.48	1.85	47.22	0.50	47.72
River Vale, N. J.	1893–1904	12	2	17	50.27	48.62	1.65	49.84	0.28	50.12
Englewood, N. J.	1896–1904	5	2	40	52.22	49.70	2.52	51.61	1.01	52.62
Paterson, N. J.	1892–1904	13	3	23	51.79	49.86	1.93	51.21	0.44	51.65
Dover, N. J.	1886–1905	20	8	40	51.29	47.72	3.57	47.31	1.43	48.74
Canton, Conn.	1889–1904	16	6	38	51.35	48.53	2.82	49.07	1.07	50.14
Waterbury, Conn.	1889–1904	15	8	53	50.78	46.82	3.96	46.62	2.10	48.72
New Haven, Conn.	*1887–1904*	*18*	*6*	*33*	*45.29*	*42.73*	*2.56*	*42.35*	*0.84*	*43.19*
Hartford, Conn.	1888–1904	15	6	40	51.24	48.28	2.96	47.79	1.18	48.97
Hawleyville, Conn.	1899–1904	6	3	50	52.60	49.08	3.52	50.79	1.76	52.55
Amherst, Mass.	1887–1904	14	3	21	45.09	43.95	1.14	43.56	0.24	43.80
Monson, Mass.	1890–1904	14	4	29	46.48	44.75	1.73	44.94	0.50	45.44
Williamstown, Mass.	1855–1904	35	14	40	39.39	37.27	2.12	37.30	0.85	38.15
Manchester, Vt.	1888–1904	6	1	17	43.96	43.33	0.63	41.95	0.11	42.06
Jacksonville, Vt.	1889–1904	13	8	62	48.06	43.58	4.48	44.92	2.78	47.70
Kinderhook, N. Y.	1830–1846	17	4	24	36.19	35.17	1.02	36.00	0.24	36.24
West Point, N. Y.	1843–1899	48	20	42	46.55	43.78	2.77	43.69	1.16	44.85
Kingston, N. Y.	1829–1892	23	8	35	39.28	37.64	1.64	37.45	0.57	38.02
Kingston Reservoir, N. Y.	1900–1905	6	3	50	48.41	44.77	3.64	46.94	1.82	48.76
Poughkeepsie, N. Y.	1830–1899	24	11	46	38.09	36.16	1.93	37.71	0.89	38.60
Oxford, N. Y.	1829–1905	39	7	18	40.81	39.80	1.01	41.89	0.18	42.07
Hudson, N. Y.	1827–1855	19	5	26	39.18	36.20	2.98	35.49	0.77	36.26
Hartwick, N. Y.	1826–1850	14	2	14	37.31	36.63	0.68	35.56	0.10	35.66
Hamilton, N. Y.	1827–1895	19	4	21	34.12	33.26	0.86	32.93	0.18	33.11
Cooperstown, N. Y.	1854–1905	52	10	19	39.81	38.92	0.89	38.36	0.17	38.53
Granville, N. Y.	1835–1848	13	3	23	31.86	30.65	1.21	30.96	0.28	31.24
Fairfield, N. Y.	1828–1848	16	5	31	36.69	34.90	1.79	84.55	0.55	35.10
Cherry Valley, N. Y.	1827–1845	14	4	29	41.31	40.31	1.00	40.31	0.29	40.60
Rome, N. Y.	1890–1904	13	5	38	47.06	44.84	2.22	45.83	0.84	46.67
Wappingers Falls, N. Y.	1891–1905	15	5	33	50.36	46.60	3.76	48.13	1.24	49.37
Middletown, N. Y.	1891–1905	9	3	33	45.73	42.99	2.74	44.11	0.90	45.01
Cortland, N. Y.	1851–1905	24	7	29	41.21	39.33	1.88	39.53	0.55	40.08
Mount Pleasant, N. Y.	1831–1844	12	5	42	36.19	34.68	1.51	35.75	0.63	36.38
Gloversville, N. Y.	1893–1905	13	3	23	44.31	43.32	0.99	44.78	0.23	45.01
Binghamton, N. Y.	1891–1905	15	2	13	34.00	33.50	0.50	34.60	0.07	34.67
Montgomery, N. Y.	1828–1842	13	5	38	34.93	32.77	2.16	32.45	0.82	33.27
Liberty, N. Y.	1851–1904	13	7	54	47.11	44.57	2.54	45.56	1.37	46.93
Greenwich, N. Y.	1898–1905	7	0	0	37.72	37.72	0.00	46.42	0.00	46.42
Lake Hill, N. Y.	1903–1905	3	1	33	49.04	48.62	0.42	52.73	0.14	52.87
Oneonta, N. Y.	1895–1905	9	2	22	39.40	38.54	0.86	41.42	0.19	41.61
Catskill, N. Y.	1897–1900	3	0	0	38.46	38.46	0.00	38.46	0.00	38.46
Middleburg, N. Y.	1889–1891	3	0	0	38.12	38.12	0.00	35.80	0.00	35.80
Windham, N. Y.	*1900–1905*	*6*	*3*	*50*	*40.74*	*37.70*	*3.04*	*38.84*	*1.52*	*40.36*
South Hartford, N. Y.	1864–1878	12	5	42	41.13	38.13	3.00	36.50	1.26	37.76
Lansingburg, N. Y.	1826–1846	20	9	45	33.45	31.43	2.02	31.75	0.91	32.66
Glens Falls, N. Y.	1879–1905	26	6	23	37.65	36.30	1.35	36.68	0.31	36.99
South Kortright, N. Y.	1889–1905	14	2	14	39.79	39.38	0.41	40.03	0.06	40.09
West Berne, N. Y.	1903–1905	3	0	0	34.05	34.05	0.00	36.78	0.00	36.78
Red Hook, N. Y.	1902–1903	2	0	0	53.09	53.09	0.00	51.67	0.00	51.67
Port Jervis, N. Y.	1890–1905	16	3	19	48.99	47.65	1.34	48.71	0.25	48.96
North Salem, N. Y.	1830–1859	22	10	45	41.34	39.91	1.43	39.91	0.64	40.55
Carvers Falls, N. Y.	1899–1905	6	0	0	35.42	35.42	0.00	37.55	0.00	37.55
New Lisbon, N. Y.	1891–1905	15	3	20	40.16	39.35	0.81	40.64	0.16	40.80
Delhi, N. Y.	1828–1852	3	1	33	40.05	37.93	2.12	39.10	0.70	39.80
Griffins Corners, N. Y.	1901–1905	5	1	20	43.94	42.43	1.51	43.46	0.30	43.76
Athens, N. Y.	1903–1905	3	0	0	38.61	38.61	0.00	41.64	0.00	41.64
Mohonk, N. Y.	1891–1905	12	6	50	50.97	47.43	3.54	48.48	1.77	50.25
Newburgh, N. Y.	1828–1867	20	10	50	36.08	34.01	2.07	34.01	1.04	35.05

In order to show that the isohyetal lines as drawn on the watersheds differ but very slightly from the most probable values of the rainfall at each of the stations, three diagrams, figs. 2, 3, and 4 are submitted.

Fig. 2 shows what may be called a vertical section north and south along the Hudson River, from New York to Troy. On this diagram are plotted the observed values of the rainfall and also the values as read from the isohyetal lines on the map. It will be noted that the greatest difference occurs at Catskill, where it amounts to 8 per cent. Fig. 3 may be called a vertical section east and west, approximately thru Binghamton, N. Y., on the west, and Amherst, Mass., on the east. The greatest difference between the observed rainfall and that from the isohyetal lines again occurs at Catskill, where the difference is again 8 per cent. In fig. 4, which is a section east and west thru Towanda, Pa., on the west and Hartford, Conn., on the east, the greatest difference is shown to be less than 3 per cent. Where the words "observed rainfalls" are used in these figures and in the foregoing description, it must be remembered that they are the observed rainfalls as modified in the manner hereinbefore described.

In order further to justify the isohyetal lines as drawn on the map submitted herewith, a tracing was made showing as points only the positions of those stations having records of fifteen years or more in length, and the isohyetal lines were drawn among them strictly as a problem in contours. The results so obtained differed in no essential particular from those obtained by drawing in the lines and giving consideration to all records, no matter what their length. As a test of the method this was a particularly severe one, and the close agreement was a matter of much gratification.

As indicating, in a general way, the correctness of the result for the most probable value of the mean rainfall on the Esopus watershed, the following table showing the average rainfall for the Esopus as given by the average of seven gages, and as deduced from the New York and Albany records, has been prepared. It covers a period of but six months, and can therefore be considered as having a minor value only. It is offered, however, for what it may be worth.

Station.	1905.			1906.			Total.
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Albany	2.38	1.49	1.36	0.97	2.09	2.54	10.83
New York	2.67	1.67	3.67	2.98	2.57	5.58	19.14
Esopus, observed	4.17	2.30	3.74	2.73	2.35	4.78	20.07
Esopus—New York	2.67	1.67	3.67	2.98	2.57	5.58	19.14
Esopus—Albany	2.76	1.73	1.58	1.13	2.42	3.06	12.68

The theory has been advanced that the rainfall of these watersheds is large, owing to their comparatively great elevation. We believe that there is a zone of large rainfall which is the result of the influence of the mountains, but we believe also, on the contrary, that the watersheds under consideration, with the possible exception of Rondout, are outside of this zone. This is evidenced by all of the rainfall records now available, and would appear to be due to the cooling of the storm winds to below the dew-point before the mountain slopes are entirely reached, i. e., the mountain influences make themselves felt before the mountains themselves are reached by the storm winds. Precipitation is thus begun before the winds have traversed the high lands, and the zone of greatest rainfall lies around and not on or beyond the higher elevations.

We believe that the values of the probable mean annual rainfalls on the Catskill watersheds as derived in this discussion are the best that can be deduced from any data now available or in existence.

The values of the most probable mean annual rainfall on these watersheds having been determined and the actual most

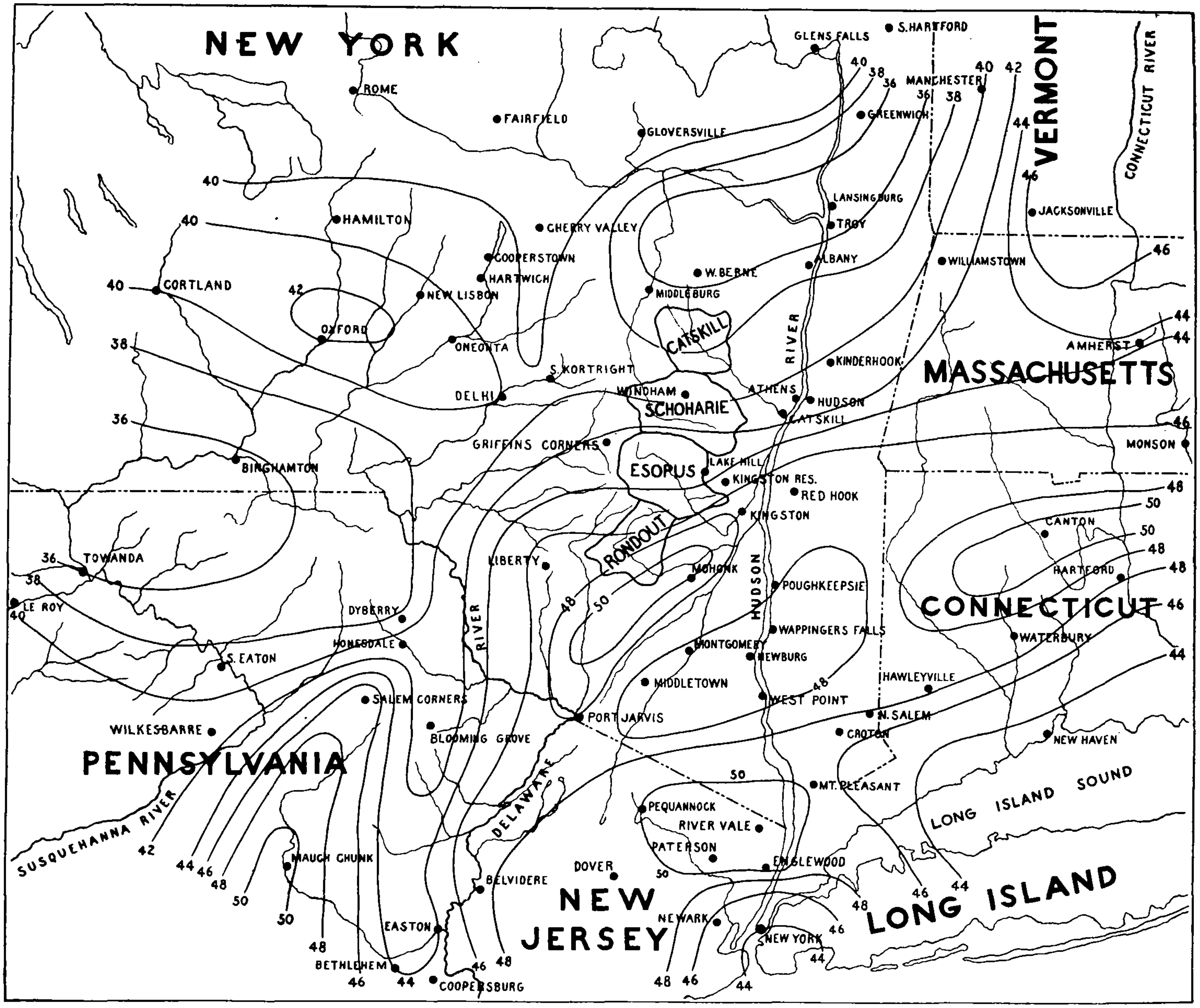

FIG. 1.—Map of the Catskill Mountain region and vicinity, showing by isohyetal lines the probable mean annual rainfall.

probable values of the rainfall at other points being known, it became easy to transfer their yearly rainfalls to each of the watersheds. Thus for the Esopus, where the rainfall is 44 inches, it can be said that the rainfall in any year was 44/38 of the rainfall during that year at Albany, or that it was 44/47 of that on the Croton watershed; 38 and 47 being the most probable values of the mean annual rainfall at Albany and on the Croton.

This method is probably of reasonable accuracy, but we desire to point out that it is not entirely satisfactory, inasmuch as it transfers the local characteristics of the rainfall at Albany or on the Croton to the locality being studied. We believe that each locality has its own characteristics, but in the absence of any direct observations the method followed is the best available.

RUN-OFF.

The run-off from a watershed is the water that appears in the stream which drains the watershed and becomes available for use. It is the difference between the rainfall and the evaporation, if in this latter term there be included all water required by the vegetation, and also that required and used by all other natural causes.

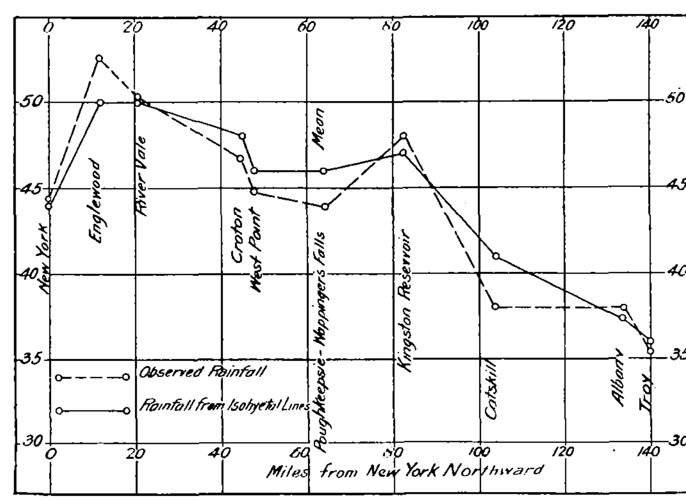

FIG. 2.—Rainfall values along a south-north line from New York to Troy, N. Y.

TABLE 2.—*Deduced mean annual dependable precipitation derived by the use of the contemporaneous precipitation in the vicinities of New York and Albany.*

Place.	Time of record.	Length of record.	Mean dependable precipitation.	Precipitation during same period in vicinity of—		Mean precipitation from—		Deduced mean annual dependable precipitation.
				New York.	Albany.	New York.	Albany.	
		Years.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Vicinity of New York	1836–1905	70	44.07	44.07	...	44.07	...	44.07
Vicinity of Albany	1825–1904	80	36.34	...	36.34	...	36.34	36.34
Croton watershed	1868–1904	37	46.73	44.98	36.70	45.55	46.26	45.91
Pequannock watershed	1893–1905	13	47.71	45.00	33.98	46.73	51.18	48.95
Le Roy, Pa	1889–1905	17	40.12	44.99	34.98	39.29	41.66	40.47
Dyberry, Pa	1866–1898	25	39.00	44.77	37.28	38.42	38.01	38.22
Blooming Grove, Pa	1866–1894	27	39.80	44.44	37.09	39.48	39.13	39.30
Towanda, Pa	1896–1905	10	35.20	45.32	34.17	34.24	37.41	35.82
Easton, Pa	1857–1905	26	43.71	46.09	35.60	41.91	44.55	43.23
Mauch Chunk, Pa	1890–1905	14	48.74	44.30	34.40	47.41	51.52	49.46
South Eaton, Pa	1890–1905	16	38.32	44.97	34.68	37.57	40.16	38.87
Salem Corners, Pa	1870–1899	9	48.39	45.10	37.33	47.30	47.12	47.21
Bethlehem, Pa	1878–1903	26	42.19	44.93	36.35	41.40	44.93	43.17
Coopersburg, Pa	1890–1900	11	46.48	44.43	34.51	46.38	48.97	47.67
Wilkes-Barre, Pa	1885–1905	17	38.84	44.78	34.41	38.13	41.01	39.57
Belvidere, N. J	1892–1904	11	45.48	43.85	33.92	45.71	48.74	47.22
Dover, N. J	1886–1905	20	47.72	45.78	35.67	45.97	48.65	47.31
Honesdale, Pa	1882–1894	13	41.75	46.01	37.13	40.00	40.85	40.42
River Vale, N. J	1893–1904	12	48.62	45.04	33.99	47.57	52.11	49.84
Kinderhook, N. Y	1830–1846	17	35.17	...	35.52	...	36.00	36.00
New York, N. Y	1836–1905	70	43.71	44.07	...	43.71	...	43.71
Newark, N. J	1844–1904	61	44.62	44.07	...	44.62	...	44.62
West Point, N. Y	1843–1899	48	43.78	44.29	36.36	43.60	43.78	43.69
Kingston, N. Y	1829–1892	23	37.64	...	36.52	...	37.45	37.45
Poughkeepsie, N. Y	1830–1899	24	36.16	...	35.79	...	37.71	37.71
Albany, N. Y	1826–1904	79	37.31	...	36.34	...	37.31	37.31
Troy, N. Y	1826–1886	59	35.18	...	36.34	...	35.18	35.18
Oxford, N. Y	1829–1905	39	39.80	...	34.79	...	41.89	41.89
Hudson, N. Y	1827–1855	19	36.20	...	37.21	...	35.49	35.49
Hartwick, N. Y	1826–1850	14	36.63	...	37.52	...	35.56	35.56
Hamilton, N. Y	1827–1895	19	33.26	...	36.80	...	32.93	32.93
Cooperstown, N. Y	1854–1905	52	38.92	45.42	36.26	37.79	38.92	38.36
Granville, N. Y	1835–1848	13	30.65	...	35.86	...	30.96	30.96
Fairfield, N. Y	1828–1848	16	34.90	...	36.53	...	34.55	34.55
Cherry Valley, N. Y	1827–1845	14	40.31	...	36.18	...	40.31	40.31
Englewood, N. J	1896–1904	5	49.70	44.65	33.52	49.20	54.02	51.61
Rome, N. Y	1890–1904	13	44.84	44.90	34.17	43.96	47.70	45.83
Canton, Conn	1889–1904	16	48.53	45.02	34.98	47.58	50.55	49.07
Waterbury, Conn	1889–1904	15	46.82	45.29	35.46	45.46	47.78	46.62
New Haven, Conn	1887–1904	18	42.73	45.77	35.76	41.09	43.60	42.35
Hartford, Conn	1888–1904	15	48.28	45.96	35.69	46.42	49.16	47.79
Amherst, Mass	1887–1904	14	43.95	45.68	35.51	42.26	44.85	43.56
Wappingers Falls, N. Y	1891–1905	15	46.60	44.63	33.86	46.14	50.11	48.13
Middletown, N. Y	1891–1905	9	42.99	44.65	33.35	42.57	45.65	44.11
Jacksonville, Vt	1889–1904	13	44.19	44.92	34.41	43.32	46.52	44.92
Cortland, N. Y	1851–1905	24	39.33	47.12	33.93	36.76	42.29	39.53
Mount Pleasant, N. Y	1831–1844	12	34.68	...	35.18	...	35.75	35.75
Gloversville, N. Y	1893–1905	13	43.32	45.00	33.45	42.47	47.09	44.78
Binghamton, N. Y	1891–1905	15	33.50	44.62	33.86	33.17	36.02	34.60
Montgomery, N. Y	1828–1842	13	32.77	...	36.67	...	32.45	32.45
Liberty, N. Y	1851–1904	13	44.57	44.96	34.21	43.70	47.41	45.56
Greenwich, N. Y	1898–1905	7	46.51	46.51	34.60	43.88	48.96	46.42
Lake Hill, N. Y	1903–1905	3	48.62	44.76	30.78	48.14	57.32	52.73
Paterson, N. J	1892–1904	13	49.86	44.68	34.05	49.37	53.04	51.21
Oneonta and Bloomville, N. Y	1895–1905	9	38.54	44.06	31.64	38.54	44.30	41.42
Catskill, N. Y	1897–1900	3	38.46	44.26	36.16	38.46	38.46	38.46
Middleburg, N. Y	1889–1891	3	38.12	46.50	39.02	35.96	35.63	35.80
Windham, N. Y	1900–1905	6	37.70	45.62	33.03	36.25	41.43	38.84
South Hartford, N. Y	1864–1878	12	38.13	46.96	37.59	35.97	37.02	36.50
Manchester, Vt	1888–1904	6	43.33	47.39	35.92	40.12	43.77	41.95
Lansingburg, N. Y	1826–1846	20	31.43	...	36.03	...	31.75	31.75
Glens Falls, N. Y	1879–1905	26	36.30	44.46	35.20	35.94	37.42	36.68
South Kortright, N. Y	1889–1905	14	39.38	45.04	34.89	38.61	41.45	40.03
West Berne, N. Y	1903–1905	3	34.05	44.76	30.77	33.50	40.05	36.78
Red Hook, N. Y	1902–1903	2	53.09	47.51	35.78	49.17	54.17	51.67
Port Jervis, N. Y	1890–1905	16	47.65	44.91	34.20	46.72	50.69	48.71
Monson, Mass	1890–1904	14	44.90	45.22	35.17	43.59	46.29	44.94
Hawleyville, Conn	1899–1904	6	49.08	45.52	33.35	47.65	53.93	50.71
North Salem, N. Y	1830–1859	22	39.91	...	36.33	...	39.91	39.91
Carvers Falls, N. Y	1899–1905	6	35.42	45.20	31.55	34.39	40.71	37.55
New Lisbon, N. Y	1891–1905	15	39.35	44.62	33.86	38.96	42.31	40.64
Delhi, N. Y	1828–1852	3	37.93	...	35.21	...	39.10	39.10
Griffins Corners, N. Y	1901–1905	5	42.43	45.94	33.52	40.80	46.12	43.46
Athens, N. Y	1903–1905	3	38.61	44.76	30.78	37.85	45.42	41.64
Mohonk, N. Y	1891–1905	12	47.43	44.81	34.20	46.50	50.46	48.48
Newburgh, N. Y	1828–1867	20	33.54	...	36.20	...	33.54	33.54
Williamstown, Mass	1855–1904	35	37.27	45.42	35.11	36.18	38.42	37.30
Kingston Reservoir No. 1, N. Y	1900–1905	6	44.77	45.62	33.03	44.73	49.15	46.94

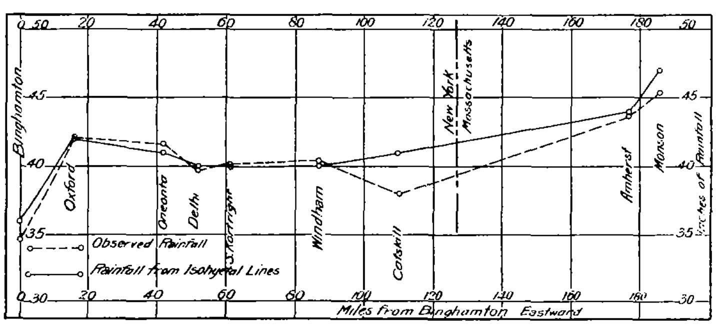

FIG. 3.—Rainfall values along a west-east line from Binghamton, N. Y., to Monson, Mass.

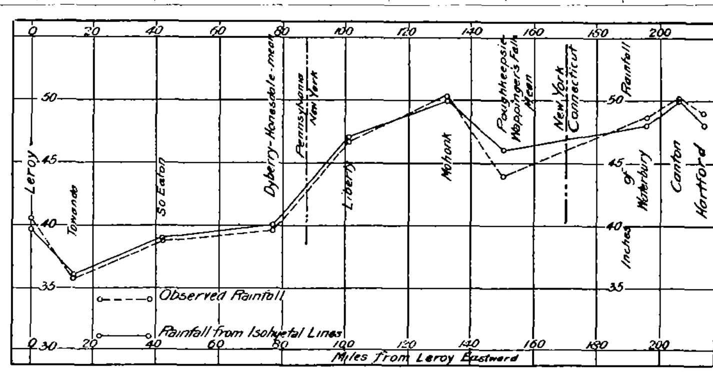

FIG. 4.—Rainfall values along a west-east line from Le Roy, Pa., to Hartford, Conn.

TABLE NO. 3.—*Showing that the rainfall at any station within 100 miles of the Ashokan reservoir will, for 72 per cent of the time, vary from its mean by practically the same percentage as that at any other station also within the same distance*

Stations.	Mean dependable.						1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842
Albany	37.31						127	97	103	98	106	120	92	87	109	108	100	102	102	120	102	124
Hudson	36.20						110	104	92		123	126	105	84	95							98
Kingston	37.64								103	107	117	102	114	95	90	98	90	99	90	87	98	90
New York	43.71															63	107	96	98	68	96	78
Average							118	100	99	102	115	116	104	89	98	90	99	99	97	92	99	98

		1843	1844	1845	1846	1847	1848	1849	1850	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863
Albany	37.31	130	87	109	102	112	117	93	125	93	85	112	81	100	97	101	92	86	87	97	96	116
Hudson	36.20	110	90	72	71	105	92	78			100	107		137								
Kingston	37.64			89	94	101	101	86														
New York	43.71	76	83	78	112	123	84	73	112	93	100	119	90	121	93	102	119	117	103	125	114	126
West Point	43.78	108	112	99	85	80	113	88	125	93	83	125	108	104	91	102	98	100	110	90	99	112
Liberty	44.57									97	99	124	100	103	83	114	90	103	101			
Cooperstown	38.92												98	118	76	134	116	106	87	110	98	118
Average		106	93	89	93	104	101	84	121	94	93	117	95	114	88	111	103	102	98	106	102	118

		1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884
Albany	37.31	75	98	92	102	96	93	124	116	105	106	100	103	103	88	133	104	87	98	91	106	105
Hudson	36.20																					
Kingston	37.64																					
New York	43.71	109	129	105	110	133	104	90	117	97	99	87	94	84	92	111	89	84	83	82	89	125
West Point	43.78	85	93	90	103	85	109	97	110	105	102	92	101	110	95	102	97	77	106			
Liberty																						
Cooperstown	38.92	77	91	83	83	96	118	85	93	95	106	94	97	96	89	100	78	88	87	79	92	90
Dyberry	39.00			93			95		97	87	101	82	77			109	85	83	96	95	89	107
Croton	46.60					93	92	96	105	87	94	91	82	87	98	120	101	79	100	92	92	110
Bethlehem	42.19															104	93	81	83	98	106	110
Average		87	103	93	100	101	102	98	106	96	101	91	92	96	92	111	92	83	93	90	97	108

		1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905
Albany	37.31	82	92	107	120	106	106	103	94	95	94	80	75	110	104	78	82	102	101	92	84	72
Hudson	36.20																					
Kingston	37.64					119	109	112	101													
New York	43.71	96	107	107	121	108	109	95	87	121	101	82	87	89	103	96	95	108	108	99	95	102
West Point	43.78							87	96	112	92	107	105	102	118	102						
Liberty	44.57							92												101	81	
Cooperstown	38.92	86	85	92	98	99	100	105	111	115	97	95	101	119	118	97	106	118	104	114	103	117
Dyberry	39.00	99	97	117	129		136	106	103	115	93	74			130							
Croton	46.60	94	102	109	117	110	116	91	95	109	101	87	98	98	109	97	105	114	119	114	104	98
Bethlehem	42.19	85	105	102	100	115	121	104	85	95	88	78	105	100	105	93	81	109	127	122		
Dover	47.72		90	98	113	105	100	104	81	110	91	74	93	104	101	95	89	96	127	121	102	101
Amherst	43.95			114	124	101	111	99	83	96	73	92	94		115	95				101	103	
Waterbury	46.82					98	110	92	86	109	93	97		98	108	87	91	114	118	107	94	
South Kortright	39.38					106	114	96	91	109	89	81	86	109	107				121	100	92	97
Binghamton	33.50							118	115	119	113	91	101	99	118	70	67	98	96	111	90	93
Mohonk	47.43							108	108	98	93		90	86			100	102	128	111	97	83
Pequannock	47.71									104	96	77	102	102	107	100	88	100	126	112	95	91
Windham	37.70																87	104	119	108	98	83
Griffins Corners	42.43																	94	121	104	90	91
Lake Hill	48.62																			119	93	88
Average		90	97	106	115	107	112	100	95	108	95	79	95	101	111	92	90	105	116	108	95	93

In order to determine the run-off, then, it becomes necessary first to determine the evaporation, which is dependent in some measure on each of the following conditions:

a.—The rainfall.

b.—The extent of the watershed.

c.—The extent of water surface on the watershed.

d.—The barometric pressure.

e.—The mean daily atmospheric temperature.

f.—The mean annual atmospheric temperature.

g.—The wind velocity.

h.—The inclination of the watershed.

i.—The geological character of the watershed.

j.—The extent of forest area on the watershed.

k.—The extent of cultivated land on the watershed.

All these conditions, and possibly some others, operate to render the problem a difficult one, and as yet no successful attempt has been made to devise a formula which will apply to more than one or two certain watersheds.

The following are the general laws of evaporation:

1. All other things being equal, for a rainfall uniformly distributed thruout the year, the evaporation will increase proportionally with the rainfall.

2. All other things being equal, a heavy winter and a light summer rainfall will together show a small annual evaporation, and conversely.

3. All other things being equal, the greater the watershed the greater will be the evaporation.

4. All other things being equal, the greater the area of water surface on the watershed the greater will be the evaporation.

5. All other things being equal, the evaporation varies nearly inversely as the atmospheric pressure, or, it varies also nearly directly as the altitude of the watershed.

6. All other things being equal, the rate of evaporation is nearly proportional to the difference of the temperatures indicated by the wet-bulb and the dry-bulb thermometers.

7. All other things being equal, the capacity of atmospheric air for moisture is approximately doubled for each 20° F. increase in atmospheric temperature; the evaporation will therefore be in some measure increased by an increase in temperature.

8. All other things being equal, the evaporation varies nearly directly as the wind velocity.

9. All other things being equal, the evaporation from a watershed will vary approximately inversely as the square root of the sine of the angle of its average inclination to the horizon.

10. All other things being equal, the evaporation from a watershed will vary nearly as the extent of the surface it exposes. The extent of the surface it exposes is nearly proportional to its area divided by the cosine of the angle of its average inclination.

11. All other things being equal, the evaporation will vary nearly inversely as the porosity of the materials with which the watershed is covered.

12. All other things being equal, the evaporation will vary approximately with the extent of cultivated land on the watershed.

13. All other things being equal, the evaporation will vary approximately inversely with the extent of forest area on the watershed.

Vermeule in his report of 1894 to the geological survey of New Jersey made an extended study of the subject, and deduced an expression for the evaporation in which it was made to depend on the rainfall and on the mean annual atmospheric temperature of the watershed. This formula has been severely criticized by Rafter in his paper on "The relation of rainfall to runoff", U. S. Geological Survey Water Supply and Irrigation Paper No. 80, but the ground of the criticism, in view of the many causes which act to modify evaporation, appears to us to have no foundation.

Vermeule's formula is as follows:

E = yearly evaporation.
R = yearly rainfall.
T = mean annual temperature.
$F = (0.05\,T - 1.48)$ = factor = 1.00 for 49.7° F.
$E = F\,(15.50 + 0.16\,R)$.

In monthly form this formula becomes

e = monthly evaporation.
r = monthly rainfall.
F = factor as heretofore.

January,	$e = F\ (0.27 + 0.10\,r)$.
February,	$e = F\ (0.30 + 0.10\,r)$.
March,	$e = F\ (0.48 + 0.10\,r)$.
April,	$e = F\ (0.87 + 0.10\,r)$.
May,	$e = F\ (1.87 + 0.20\,r)$.
June,	$e = F\ (2.50 + 0.25\,r)$.
July,	$e = F\ (3.00 + 0.30\,r)$.
August,	$e = F\ (2.62 + 0.25\,r)$.
September,	$e = F\ (1.63 + 0.20\,r)$.
October,	$e = F\ (0.88 + 0.12\,r)$.
November,	$e = F\ (0.66 + 0.10\,r)$.
December,	$e = F\ (0.42 + 0.10\,r)$.

$$E = F\,(15.50 + 0.16\,R).$$

While we do not agree with Mr. Vermeule in the manner of the determination of the factor to be used for any watershed, we do think that the shape of his formula, when put into the monthly form he proposes, could not easily be improved upon. The most striking feature of this formula is that it takes account of the effect on the evaporation of unequal distribution of rainfall thruout the year.

Mr. Vermeule in his formula made this factor dependent entirely on the mean annual temperature, on the assumption that, as the capacity of atmospheric air for moisture is approximately doubled for each 20° F. increase in atmospheric temperature, therefore the evaporation would be doubled for each such increase in temperature.

We do not believe that such is the case, and in support of this belief submit fig. 5, on which is plotted the percentage of rainfall evaporated for each of Rafter's three seasons as given in his paper heretofore referred to, for the Croton, Pequannock, and Sudbury watersheds. The temperatures on which these percentages were plotted were obtained from the U. S. Weather Bureau publications.

The remarkable parallelism of these lines indicates primarily the existence of a well-defined law, and secondarily, that the observations have been well made. The law defined by this diagram is that for each degree increase in temperature the rainfall evaporated will be increased by very nearly 2 per cent. But it at once becomes apparent that the percentage increase in total evaporation will vary with the temperature, and we have plotted a curve as fig. 6 to define this variation.

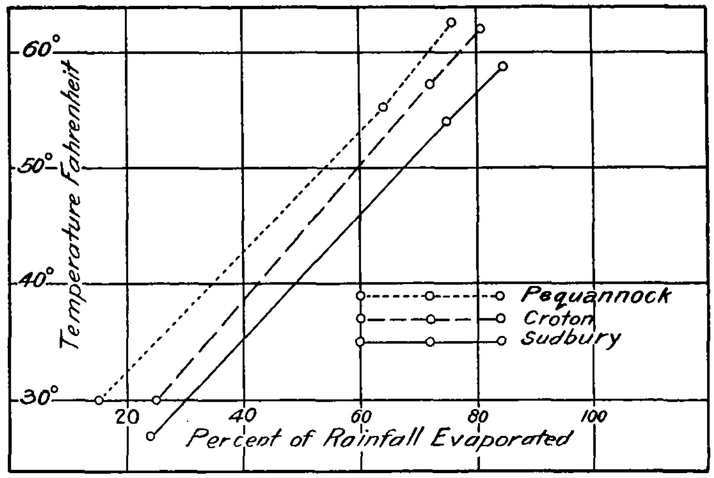

FIG. 5.—Percentage of rainfall evaporated at different temperatures from the Croton, Pequannock, and Sudbury watersheds.

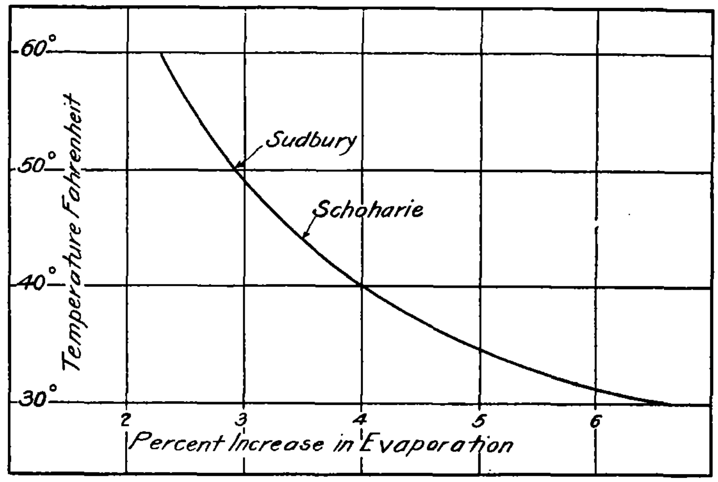

FIG. 6.—Variation of percentage increase of evaporation with change of temperature.

The mean annual temperature on the Sudbury is 49° F. and on the coldest of the Catskill watersheds, 44° F. In fig. 6 the increase in total evaporation between these limits averages 3.2 per cent, and this is the value that we believe to be correct for these studies, rather than 5 per cent as proposed by Vermeule.

Taking up now, in order, the general laws of evaporation, we see that laws 1 and 2 are fully provided for by the form of the expression we have adopted. Law 3 does not seem susceptible of adaptation to a numerical expression. Law 4 is easily provided for outside the formula by increasing the evaporation by the difference due to any increase in water surface.

Law 5 can be adapted directly by assuming some watershed as a standard and stating that the evaporation from any other watershed will be inversely as the atmospheric pressure upon it.

Practically no data are at hand concerning law 6, but it is a well-known fact that the air on the higher altitudes averages drier than on low lands, and we have therefore assumed that the difference in evaporation due to this cause (the dryness of the air) will be one-fourth that due to the difference occasioned by difference in barometric pressure and in the same direction.

Law 7 has already been fully discust and the results stated.

On account of the absence of any knowledge of wind velocities, we are unable to apply the fact stated in law 8. It would seem, however, that any difference due to this cause would be slight.

Law 9 is here proposed by us as being an approximation to the reasonable belief that steep watersheds will yield a greater proportion of the rainfall than will comparatively flat ones. This statement was put into the above form on account of the not unreasonable analogy between the flow of water in a channel and the flow both over the ground and in the creeks of a watershed. The steeper the watershed the more rapidly will the rain water run off, and therefore less time will be afforded the evaporation to reduce the volume.

In order to apply this principle, it becomes necessary to define the words "average inclination of the watershed", and it seemed to us proper to assume that if the watershed were square its average inclination would be the difference in vertical height between its highest and lowest points divided by the diagonal of the square. Table 4 has been prepared with a view to indicating the difference in slope of the Croton, the Pequannock, the Sudbury, and the Esopus watersheds. The square root of the sine of each of their average inclinations has been determined. The average inclinations of the Croton and Sudbury are practically the same, and the inclination of the Esopus is twice as great as either.

TABLE 4.—*Mean slope of four watersheds.*

Watershed.	Total dip.	Length of diagonal.	Mean slope per mile.	Angle.	Sin.	$\sqrt{\sin}$.
	Feet.	*Miles.*	*Feet.*	° ′		
Croton	1,100	26.38	83	0 54	.0156	.125
Sudbury	550	12.40	89	0 55	.0160	.126
Pequannock	900	11.00	164	1 45	.0305	.174
Esopus	3,800	22.47	339	3 41	.0640	.253

As indicating the general correctness of this result, we quote from the report of the Commission on Additional Water Supply, page 234:

"The table shows that the Esopus yielded from the floods after the great drought a proportion of the rainfall just twice as great as that of the Croton".

While the method is therefore applicable to the heavy floods, it is of course entirely inapplicable to moderate rainfalls. Now one and one-half inches is a reasonably heavy fall of rain, and in each year in these latitudes there occur on an average about eight such rains, which aggregate about eleven inches, or about 25 per cent of the total yearly rainfall. We feel, therefore, that this principle is applicable to the extent of 25 per cent of its full value for all cases.

Law 10 is of little value, and has been stated only for the sake of completeness.

Law 11 treats of the character of the soil. A watershed covered with loose gravel and sand will usually show a greater yield than one with a clay cover, as the rainfall sinks into the more porous material, and is in this manner largely protected against evaporation until it again finds its way into the streams thru springs or underground channels. All of the Catskill watersheds, with the possible exception of the Catskill, are fairly well covered with a loose rock covering on the mountain slopes, while the lower reaches of the valleys are filled with deposits of gravel. The intermediate lands are covered with an iceberg clay and do not afford much opportunity for water to penetrate into them. It does not appear to us that these watersheds are remarkable either for the presence or for the absence of opportunity for water to protect itself against evaporation by percolating into and thru the subsoil. In any event, it does not appear likely that this law could ever be numerically applied to a watershed.

In order to bring these laws down to actual figures, it is now necessary that we have the characteristics of the watersheds before us, and for purposes of comparison we have added also the same data for the Croton, Sudbury, and Pequannock watersheds.

Watersheds.	Area.	Average altitude.	Average barometer.	Mean temperature.	$\sqrt{\text{sine average slope}}$.	Rainfall.
	sq. m.	*Feet.*	*Inches.*	° *F.*		*Inches.*
Esopus	255	1700	28.1	45	.253	44
Schoharie	228	2000	27.8	44	.160	41
Rondout	131	1600	28.2	47	.211	48
Catskill	163	1500	28.3	46	.153	38
Pequannock	62	1100	28.7	48	.174	50
Croton	339	600	29.3	49	.125	47
Sudbury	78	350	29.6	49	.126	46

Now, under law 5, if we assume the Croton as a standard, we find that the evaporation on each of the other watersheds will be as follows:

Esopus...... 4.5 per cent greater than Croton.
Schoharie.... 6.5 per cent greater than Croton.
Rondout..... 4.5 per cent greater than Croton.
Catskill...... 3.5 per cent greater than Croton.
Pequannock . 2.3 per cent greater than Croton.
Sudbury..... 0.6 per cent less than Croton.

Under law 6 and our assumption, we find that the evaporation will be as follows:

Esopus...... 1.1 per cent greater than Croton.
Schoharie.... 1.6 per cent greater than Croton.
Rondout..... 1.1 per cent greater than Croton.
Catskill...... 0.9 per cent greater than Croton.
Pequannock . 0.8 per cent greater than Croton.
Sudbury..... 0.1 per cent less than Croton.

And under law 7 and our discussion of it, we see that the evaporation will be as follows:

Esopus...... 12.8 per cent less than Croton.
Schoharie.... 16.0 per cent less than Croton.
Rondout..... 6.4 per cent less than Croton.
Catskill...... 9.6 per cent less than Croton.
Pequannock . 3.2 per cent less than Croton.
Sudbury..... 0.0 per cent less than Croton.

Finally, under law 10 and our assumptions thereunder, we find that the evaporation is—

Esopus ...... 25.5 per cent less than on the Croton.
Schoharie.... 7.0 per cent less than on the Croton.
Rondout. .... 17.2 per cent less than on the Croton.
Catskill. ..... 5.6 per cent less than on the Croton.
Pequannock . 9.8 per cent less than on the Croton.
Sudbury. .... 0.0 per cent less than on the Croton.

Now, summing up these differences, we have the following:

Watersheds.	Barometer.	Dryness.	Temperature.	Inclination.	Total.
Esopus	+4.5	+1.1	−12.8	−25.5	−32.7
Schoharie	+6.5	+1.6	−16.0	− 7.0	−14.9
Rondout	+4.5	+1.1	− 6.4	−17.2	−18.0
Catskill	+3.5	+0.9	− 9.6	− 5.6	−10.8
Pequannock	+2.3	+0.8	− 3.2	− 9.8	− 9.9
Sudbury	−0.6	−0.1	0.0	0.0	− 0.7

This indicates that these watersheds will yield of the rain which falls upon them more than will the Croton, by the following averages:

Esopus...... 33 per cent.
Schoharie.... 15 per cent.
Rondout..... 18 per cent.
Catskill...... 11 per cent.
Pequannock . 10 per cent.
Sudbury..... 0.7 per cent.

Now in the formula we have adopted the evaporation is exprest in terms of the rainfall, and its factor for the Croton is 100 per cent. The factors which the preceding discussion leads us to use for these watersheds are, then, the difference between 100 per cent and the greater percentage of yield of each as heretofore shown.

The factors derived and used are the following:

Esopus...... 0.67
Schoharie.... 0.85
Rondout..... 0.82
Catskill...... 0.89
Pequannock . 0.90
Sudbury..... 0.993

That these factors so deduced "fit" the Pequannock, the Croton, and the Sudbury with reasonable accuracy is indicated by the following:

Watershed.	Record.	Observed run-off.	Computed run-off.	Factor.
		Inches.	*Inches.*	
Sudbury	Average, 1873–1903	22.85	22.03	0.993
Pequannock	11 years, 1893–1903	331.36	332.76	0.90
Croton	Average, 1868–1899	22.93	24.82	1.00

Table 5 is also submitted as showing in detail the agreement of the formula with the observed values of the run-off on the Pequannock.

TABLE 5.—*Observed and computed run-offs of the Pequannock River by Vermeule's formula, with a temperature factor of 0.90.*

Year.	Rainfall.	Run-off.		Per cent of run-off.	
		Observed.	Computed.	Observed.	Computed.
1893	49.73	32.79	28.57	66	57
1894	44.62	28.39	24.24	64	54
1895	36.67	18.97	17.35	51	47
1896	51.89	30.75	30.05	59	58
1897	57.97	29.37	33.98	51	59
1898	51.39	28.98	30.17	56	59
1899	47.94	26.88	26.93	56	56
1900	42.00	21.50	22.16	51	53
1901	64.69	31.94	40.47	49	63
1902	60.44	35.73	37.73	59	62
1903	64.79	46.06	41.11	71	63
1904	45.24	....	24.54	....	54
1905	43.53	....	23.21	....	53
Totals to end of 1903	....	331.36	332.76	58	58

Now, applying our formula to each of these watersheds, we find that on an average we may expect:

Watershed.	Rainfall.	Evaporation.	Run-off.	Per cent of run-off.
	Inches.			
Esopus	44	15.10	28.90	65
Schoharie	41	18.75	22.25	54
Rondout	48	19.00	28.00	58
Catskill	38	19.20	18.80	49
Pequannock	50	21.15	28.85	57
Croton	47	23.02	23.98	51
Sudbury	46	24.46	21.54	47

Diagrams submitted with the report of Mr. J. Waldo Smith, Chief Engineer to the Aqueduct Commissioners, dated January 30, 1905, indicate very clearly that the Croton, with a storage of 250,000,000 gallons per square mile, will not safely sustain a draft of more than 325,000,000 gallons per day.

The watershed of the Croton River, above the New Croton Dam, is 360 square miles, and the safe yield per square mile is, therefore, 900,000 gallons per day.

Now it is safe to assume that in extremely dry periods the run-off will be 50 per cent less than in an average period, and on this basis, all other conditions being the same, the watersheds being studied will yield the following percentages of the Croton normal yield:

Esopus....... 12 8 per cent less than Croton.
Schoharie..... 25.6 per cent less than Croton.
Rondout ..... 1.0 per cent greater than Croton.
Catskill....... 38.2 per cent less than Croton.
Pequannock .. 3.2 per cent greater than Croton.
Sudbury...... 4.2 per cent less than Croton.

And we have seen that owing to the natural features of these watersheds they will yield, for the same rainfall as on the Croton, the following percentages:

Esopus....... 32.7 per cent more than Croton.
Schoharie..... 14.9 per cent more than Croton.
Rondout ..... 18.0 per cent more than Croton.
Catskill....... 10.8 per cent more than Croton.
Pequannock .. 9.9 per cent more than Croton.
Sudbury...... 0.7 per cent more than Croton.

Now, combining these, we deduce finally that these watersheds may be expected to have a safe yield, compared to the Croton safe yield, as follows:

Esopus....... 19.9 per cent more than Corton.
Schoharie .... 10.7 per cent less than Croton.
Rondout...... 19.0 per cent more than Croton.
Catskill....... 27.4 per cent less than Croton.
Pequannock .. 13.2 per cent more than Croton.
Sudbury...... 4.9 per cent less than Croton.

And, therefore, on a storage of 250,000,000 gallons per square mile of watershed may be expected to have a safe yield as follows:

Esopus....... 1,080,000 gallons per day per square mile.
Schoharie .... 804,000 gallons per day per square mile.
Rondout...... 1,070,000 gallons per day per square mile.
Catskill....... 653,000 gallons per day per square mile.
Pequannock .. 1,010,000 gallons per day per square mile.
Sudbury...... 856,000 gallons per day per square mile.

In connection with this report certain depletion diagrams [not reproduced here] were prepared.

The first diagram shows the depletion of the proposed Ashokan Reservoir when fed by the Esopus Creek, on the basis of the Albany rainfall records. It indicates that a draft of 240,000,000 gallons per day from the 255 square miles of tributary watershed could not well be exceeded without drawing down the reservoir to a considerable extent and for long periods. The maximum depletion shown is 40,000,000,000 gallons, or 160,000,000 gallons per square mile of watershed.

In the preparation of this diagram, as well as of all others, the formula as heretofore derived was employed, except that a factor of 0.75 was used instead of those deduced. This was done for the reason that it is not, at present at least, proposed to use the Ashokan Reservoir fed by the Esopus alone, but by the Esopus and Schoharie in combination.

The factor for the Schoharie is 0.85, and that for the Esopus 0.67. In proportion to the area of these watersheds, the combined factor would be

$$0.85 \times 228 = 193.80$$
$$0.67 \times 255 = 170.85$$

$$483 \;)\; 364.65 \;(\; = 0.75$$

Increase in evaporation due to reservoir water surface was provided for in the computations on which these depletion diagrams are based by assuming that the water surface on the Schoharie would be 1000 acres and on the Esopus 10,000 acres, and the corresponding corrections were made.

The second diagram shows the conditions which would obtain in the Ashokan Reservoir when collecting from the Esopus and Schoharie watersheds under a draft of 410,000,000 gallons daily and on the basis of the Albany rainfall records. This diagram indicates a maximum depletion of 63,000,000,000 gallons, or a minimum necessary storage of 130,000,000 gallons per square mile of watershed area. It also shows that the combined safe draft from these two watersheds should not exceed 425,000,000 gallons per day, or 880,000 gallons per square mile per day.

In the preparation of all the diagrams for the Schoharie, it has been assumed that the construction will be sufficient to divert all run-off up to and including that due to 7 inches of rain per month. For greater run-off than this but 80 per cent has been counted as becoming available.

The third diagram shows the conditions which would exist in the Ashokan Reservoir when fed by the Esopus and Schoharie under a draft of 410,000,000 gallons daily, but on the basis of the Croton rainfall records. The maximum depletion indicated under these conditions is 48,000,000,000 gallons.

The fourth and fifth diagrams show the conditions which would exist in the Ashokan Reservoir when fed by the Esopus and the Schoharie when under a draft of 410,000,000 gallons daily, and on the basis of the New York rainfall records.

The maximum depletion indicated under these conditions is 60,000,000,000 gallons.

Actual gagings of the four Catskill streams under consideration have been made by the United States Geological Survey more or less continually since 1901. The results of these gagings are set forth in the various water supply and irrigation papers published by the survey. Unfortunately, no rainfall observations were made contemporaneously with these gagings. A careful examination of practically all of the gagings made by the Geological Survey in New York, New Jersey, Pennsylvania, and New England since 1902 has caused us to use them as a general guide only.

CONCLUSIONS.

Our studies, therefore, lead us to the belief that the most probable mean annual rainfalls on the Catskill watersheds are as follows: Esopus, 44 inches; Schoharie, 41 inches; Rondout, 48 inches; Catskill, 38 inches.

VARIATION OF PRECIPITATION IN THE ADIRONDACK REGION.

By ALFRED J. HENRY, Professor of Meteorology. Dated April 17, 1907.

Mr. R. E. Horton, C. E., has worked out very clearly the relative distribution of precipitation in the Adirondack region for the five years, 1901-1905. The chart which accompanies Mr. Horton's article[1] shows a region of maximum precipitation (55 inches and upward) on the southwestern slope of the Adirondacks, particularly on the foothills in Lewis, Oneida, and Herkimer counties.

The writer was recently engaged on a study of the average annual precipitation over the watershed of Lake Ontario, which includes a portion of the area considered by Mr. Horton. The epoch used in this work was 1871–1906, altho the record at a number of the observing stations covered a much longer time. It is possible, therefore, to compare the mean values for the lustrum 1901–1905 with those of the much longer epoch, 1871–1906. Accordingly there will be found in the table below a statement showing the average annual precipitation for a few stations in the Adirondack region and contiguous territory for both the long and the short periods.

Comparative averages of precipitation.

Stations.	Length of record.	Whole period, 1871–1906.	Five years, 1901–05.	Departure.
	Years.	*Inches.*	*Inches.*	*Inches.*
Oswego	54	37.4	40.0	+2.6
Lowville	40	36.3	44.3	+8.0
Utica	40	41.7	50.7	+9.0
Cooperstown	53	39.9	45.3	+5.4
Keene Valley	15	35.6	40.7	+5.1

It is clearly apparent from the above table that the lustrum 1901–1905 was one of heavy precipitation in the Adirondacks; the greatest departure, about 22 per cent of the mean annual fall, occurred near the center of the region of maximum precipitation hereinbefore mentioned. The writer has found elsewhere[2] that the extreme variation in the interior of this continent for a 10-year period is as high as 20 per cent. The variation for a 5-year period in this country has not been determined; in Germany, however, Dr. G. Hellmann[3] has found that the average maximum variation of a 5-year period for 14 stations in North Germany is 116 per cent, and for a 10-year period 109 per cent. The maximum variation for a single station for a 5-year period was 128 per cent, or 6 per cent greater than for the two stations in the Adirondack region, but the majority of the German stations showed a smaller variation. What little work has been done on this subject in the United States tends to show that the variation of the precipitation, especially in the interior, is greater than in England or Germany.

[1] Monthly Weather Review, January, 1907, Vol. XXXV, pp. 8-11.

[2] Weather Bureau Bulletin D, p. 9.

[3] Die Niederschläge in den norddeutschen Stromgebieten.

In conclusion it is proper to call attention to the fact that the chart of rainfall distribution compiled by Mr. Horton probably represents very closely the maximum amount of rain that may be expected for a 5-year period in the region under consideration. Readers of the REVIEW should be careful, however, not to be misled by supposing that the chart purports to give the average or normal values for the Adirondack region, such as would result from a century of observations.

THE TEMPERATURE IN THE FRONT AND IN THE REAR OF ANTICYCLONES, UP TO AN ALTITUDE OF 12 KILOMETERS, COMPARED WITH THE TEMPERATURE IN THE CENTRAL AREA.

By HENRY HELM CLAYTON. Dated Blue Hill Observatory, Hyde Park, Mass., March 5, 1907.

Within the two years between the summer of 1904 and that of 1906, a series of observations with *ballons-sondes* were obtained at St. Louis, Mo., under the direction of Prof. A. Lawrence Rotch, by Mr. S. P. Fergusson and myself. These small balloons carried light instruments recording temperature and pressure, and occasionally reached heights of 17 kilometers or about 11 miles. These are the only data of this kind gathered in America up to the present time, and are of much interest and value in their bearing on the problems of the upper air. One of the problems of great interest is that of the distribution of temperature in cyclones and anticyclones. In a discussion of these observations published by me in the Beiträge zur Physik der freien Atmosphäre, Band II, Heft 2, 1906, the lowest temperatures (at the earth's surface) in the anticyclones were found in the central and southeastern portions, but this distribution was so changed at the height of 8 kilometers that the lowest temperature was found in the northern quadrant of the anticyclone. The reverse of this statement is true in regard to the cyclone in which the highest temperature was found in the eastern quadrant at the ground, but in the northern quadrant at the height of 8 kilometers. This matter is one of importance in studying the mechanism of these meteors and I give in the accompanying Table 1 some of the results in the individual cases where anticyclones past centrally over the region surrounding St. Louis. In this table the temperature at any height on the day in which the maximum pressure occurred at St. Louis is taken as the standard for that height and the departures from this of the temperatures at the same heights for the day preceding and the day following are given in so far as the observations permit. In each case the observations were obtained in the evening within an hour or two of 7 p. m. The tracks of the centers of maximum pressure are given on an accompanying chart, fig. 1. On this chart a circle of 300 miles radius (about 500 kilometers) is drawn around St. Louis, and it may be seen that all the given dates of maximum pressure at St. Louis are found within this area, while the dates of the preceding and following days are found outside the circle. In every case, except that of July 24 and 25, 1905, the general direction of motion was from northwest to southeast, so that observations on the day preceding were in the southeastern half of the anticyclone and on the day following in the northwestern half. The amounts in the table showing how much the temperatures in the front and in the rear of the anticyclone differed from those in the central area are plotted graphically in the accompanying diagram, fig. 2, which shows that in general it is colder in front of the anticyclone than in the central area, up to about 8 kilometers, above which altitude it becomes warmer. Of the two cases where the temperature in the rear was compared with that in the central area, in one case, January 26, 1905, it was warmer in the rear up to about 6 kilometers, and in the other case, May 10, 1906, it was warmer in the rear up to about 10 kilometers. Above these heights the rear was colder than the central area. The most instructive case is that of May 8 to